LCA Case Studies

LCA Study and Environmental Benefits for Low Temperature Disinfection Process in Commercial Laundry

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Abstract

Background, Aims and Scope. This study aims to compare the energy requirements and potential environmental impacts associated with three different commercial laundry processes for washing microbiologically contaminated hospital and care home laundry. Thermal disinfection relies mainly on a 90°C washing temperature and hydrogen peroxide, while the chemothermal disinfection uses a combination of chemicals (mainly peracetic acid) and 70°C washing temperature. The chemical disinfection process relies on a combination of chemicals used at 40°C. Currently, chemothermal processes are the most commonly used in professional laundries. Traditional chemical processes are uncommon due to drawbacks of longer residence time and high chemical requirements. However, the innovative Sterisan chemical process based on phthalimidoperoxyhexanoic acid (PAP) – which is the key subject of this Life Cycle Assessment – was designed to overcome these technical limitations.

Methods. This study is based on a screening Life Cycle Assessment (LCA) prepared in 2002 by Öko-Institut (Germany), which was carried out following the requirements of the ISO 14040 series standards. It includes energy resource consumption, water resource consumption, climate change, eutrophication and acidification potential as relevant environmental indicators. In 2004/2005, the study was further updated and broadened to include the aquatic eco-toxicity potential, photochemical oxidant formation and ozone depletion potential in order to represent the environmental burdens associated with the chemicals used.
Based on available data, the system boundaries include detergent manufacturing, the professional wash process, waste water treatment, but excluding the laundry finishing process. The selected functional unit was 1 kg washed hygiene laundry.

Results and Discussion. The LCA indicates that the Sterisan chemical process has a lower potential environmental impact than thermal or chemothermal treatment for six out of seven key indicators. This includes a 55% lower energy and a 46% lower water consumption. The global warming potential and acidification potential are approximately halved, while the photochemical oxidant formation potential and eutrophication potential are almost reduced to one third. By contrast, for the aquatic eco-toxicity, the thermal- and chemothermal processes have an approximately 17-fold lower impact. The worse aquatic toxicity score for the Sterisan process is mainly caused by a solvent component in the formulation.

Conclusion. The comparison of the thermal, chemothermal and Sterisan commercial laundry processes shows that the Sterisan process allows for very substantial reductions in energy and water consumption, as well as significant reductions in climate change, photochemical oxidant formation potential, air acidification potential and eutrophication potential. Yet, Sterisan has a clear disadvantage with regards to aquatic eco-toxicity potential.

Recommendation and Perspective. Based on a current hygiene laundry volume of approx. 584,000 tons of linen washed per year by commercial laundries in Germany, a full substitution of the market to the Sterisan process could potentially allow a primary energy saving of ~750,000 GJ/year (roughly equivalent to the residential primary energy consumption of 23,500 German citizens or the overall energy demand of approx. 6,000 German citizens). In terms of improvements to the respective processes, the chemothermal and thermal process could benefit from a reduction of water volume, and change of detergent composition to reduce the eutrophication potential. As the washing temperature is an essential factor, only slight improvements for the energy consumption indicator can be obtained, e.g. by choosing green electricity and reducing the amount of water to be heated. The Sterisan process could be improved by lowering the solvent use, although for perspective, the current aquatic eco-toxicity score of the Sterisan process is still lower than that of a typical domestic laundry product.

Keywords: Aquatic toxicity; chemothermal process; commercial laundry; energy savings; screening LCA; thermal process; Sterisan process

Introduction

The professional laundries in Germany reached an annually turnover of 1.6 billion Euro [1], with hygiene laundries having a share of nearly 20 percent [2]. Hygiene laundry is mainly generated in hospitals and care homes, but also by food industry or washrooms. Although, the total amount of hygiene laundry produced in Germany is unknown [3], about 584,000 tonnes of hospital linen were washed in professional laundries in 2004.

The processes for washing hospital and care home laundry must help provide hygienically clean linen by eliminating the risk for cross-contamination. These wash activities require compliance with standard disinfection protocols from the German Society for Hygiene and Microbiology (DGHM) or the Robert-Koch Institut (RKI). Effective disinfection for the Sterisan process was certified by DGHM.

Reduction of wash temperature without negative impact on cleaning and hygienisation performance is an ongoing trend in the domestic laundry sector. Similarly, Hychem GmbH, a Germany-based medium sized enterprise, has developed a hygiene laundry chemical process for professional use which allows operating at lower temperatures by using newly developed washing and disinfection components (Liquisan A and B, Sterisan). A key ingredient of Sterisan is PAP, (i.e., phthalimidoperoxyhexanoic acid), a commercially available peroxyacid, displaying strong bleach activity at room temperature.

1 Goal and Scope of the Study

1.1 Goal of the LCA

Goal of this Life Cycle Assessment (LCA) was to assess and compare the environmental impact of three alternative hygiene washing processes available on the market. Herein, this study intends to provide objective information to Hychem GmbH and the overall hygiene industry sector on the positive and negative environmental impacts of the Sterisan process as compared to established hygienic washing conditions.

The LCA presented in this article was performed on behalf of Hychem GmbH, developer of the new chemical hygiene laundry process, and Procter & Gamble Eurocor NV, European sales partner of Hychem GmbH for the Sterisan process. The original LCA [4] was carried out by Öko-Institut – Institute for applied Ecology, an independent scientific research institute, in 2002 and followed the requirements of the ISO standards [5–8], including external peer review. In 2004/2005, the study was further updated and broadened to include the aquatic eco-toxicity potential, in order to better represent the environmental burdens associated with the chemicals used.

Due to limitations in system boundaries, use of partial Life Cycle Inventories for some ingredient and the selection of Life Cycle Impact methodologies, this LCA study has mainly a screening character.

1.2 Scope of the Study

1.2.1 Description of systems studied and functional unit

Laundry cleaning and disinfection can be achieved in different ways: via a high washing temperature and a low amount of chemicals (thermal processes), by using chemicals and low temperature (chemical processes) or by a combination of both (chemothermal processes). Today, chemothermal processes are the most commonly used, while chemical processes are less widespread in professional laundries due to the longer residence time required and the high concentration of the chemicals used.

The specifications of the three compared hygiene washing processes can be characterised as follows:

- The **thermal laundry disinfection process** uses a *phosphate-based detergent* for washing, *hydrogen peroxide* for disinfection and bleaching, and a washing temperature of *90°C*. The exposure time, which refers to the period of time during which the specified temperature must be maintained, for disinfection is *10 minutes*. The laundry is washed in a tunnel laundry with bath current using 8 litres of fresh water per kg laundry.
- The **chemothermal laundry disinfection process** uses a *phosphate-based detergent* for washing, *peracetic acid* for disinfection and bleaching, and a washing temperature of *70°C*. The exposure time is *10 minutes*. The laundry is washed in a tunnel laundry with bath current using 8 litres of fresh water per kg laundry.
- The **Sterisan process** uses *Liquisan A and B* solutions for washing, whilst *Sterisan* is used for disinfection and bleaching. The washing temperature is *40°C*; the exposure time is *15 minutes*. The laundry is washed in a tunnel laundry with optimised bath current (rinsing water used in the prewash area) using 4 litres of fresh water per kg laundry. The optimised bath current reuses all the rinsing water in the washing process. Unlike in the case of the established processes, the lower temperature (40°C) and the lower active oxygen content [9] does not lead to protein fixing in the prewash.

The water used for the washing process is softened and the heat energy (steam) required for the washing process is generated using in-house equipment. Further specifications of the three processes are provided in **Table 1** and **Table 2**.

All results in this study were expressed on the basis of a functional unit of 1 kilogram of washed hygiene laundry

Table 1: Specifications of the three hygiene laundry washing processes [10]

Specifications of the washing processes				
Washing temperature	90°C	70°C	40°C	
Exposure time for disinfection process	10 min	10 min	15 min	
Dosage of detergents, disinfectants and other chemicals per kg laundry				
Detergent	12 g	16 g	6 g + 1,2 g	
Disinfectants	4 g	4 g	16 g	
Other chemicals	1 g	1 g	0.5 g	
Steam input per kg laundry	600 g	452 g	98 g	
Natural gas	67%	67%	67%	Steam production calculated with [11], industrial steam with natural gas, capacity: 5–20 MW
Light oil	33%	33%	33%	Steam production calculated with [11], industrial steam with light oil, capacity: 5–20 MW
Electricity demand per kg laundry	9.38 Wh	9.38 Wh	9.38 Wh	German electricity grid [12]
Fresh water demand per kg laundry	8 l	8 l	4 l	

Table 2: Formula specifications of the three hygiene laundry processes

	Thermal process	Chemo-thermal process	Sterisan process	Comments
Detergents, disinfectants and chemicals: formula specifications				
Material inventories included				
Percentage of formula (weight basis) for LCI inclusion	*100.0*	*99.81*	*99.12*	
Alcohol (C13) ethoxylate, EO 10 [13]	X	X	X	Inventoried as alcohol (C13) ethoxylate, EO 7
Alcohol (C13) ethoxylate, EO 7 [13]	X	X	X	
Alcohol (C13) ethoxylate, EO 5 [13]	X	X	X	Inventoried as alcohol (C13) ethoxylate, EO 7
Alcohol (C13) ethoxylate, EO 3 [13]	X	X	X	Inventoried as alcohol (C13) ethoxylate, EO 7
Alcohol (C13-C15) ethoxylate propoxylate, EO 14, PO 4 [13]			X	Inventoried as alcohol (C13) ethoxylate, EO 7
Talc soap [14]	X	X		
Sodium metasilicate-pentahydrate [15]	X	X		
Sodiumdisilicate [15]	X	X		Inventoried as sodium metasilicate-pentahydrate
Pentasodiumtriphosphate [13]	X	X		
Sodiumcarbonate [16]	X	X		
Sodium hydroxide [11]			X	
Zeolite P [15]	X	X		Inventoried as zeolite A, 50% suspension, 50% powder
Carboxymethylcellulose [13]	X	X		
Fluorescer, stilben type [13]	X	X		
Fluorescer, biphenyl-distyryl type [13]			X	
Peracetic acid [4]		X		Screening inventory
Acetic acid [17]		X		
Formic acid [11]	X	X	X	
Hydrogenperoxide [11]	X	X		
Oleic acid [13]			X	Inventoried as alcohol (C13) ethoxylate, EO 7
Terpinolene [11]			X	Inventoried as n-paraffine
Polycarboxylate [17]			X	
Phthalimidoperoxyhexanoic acid (PAP) [4]			X	Screening inventory
Water	X	X	X	
Material inventories missing				
Percentage of formula (weight basis) for LCI exclusion	*0.0*	*0.19*	*0.88*	
Silicon-based antifoam			X	
Hydroxyethyldiphosphonic acid		X		
Hexadecyltrimethylammonium chloride			X	
Diethylen-triamin-pentamethylen-phosphonic acid, Na salt			X	
Nitrilotriacetate, Na-salt (NTA)			X	

(cotton) unless otherwise indicated. Since all processes have been certified to meet the German disinfection requirements defined by DGHM and / or the Robert-Koch institute, the alternatives can be seen as delivering equivalent functions.

1.2.2 Life cycle stages and system boundaries

The following life cycle stages were included in the study: detergent production, including chemical raw material supply and manufacturing of the detergent; the full washing process in professional laundries and the municipal waste water treatment (**Table 3**).

Due to data availability and quality limitations, some elements were excluded from the system boundaries. However, the systems excluded from the system boundaries were carefully considered so that they are not the highest contributors to the overall environmental burdens, or that they have

Table 3: Description of life cycle stages taken into account to compare the three hygiene laundry processes

Life Cycle stage	Included	Excluded	Comments
Energy supply	External: extraction of energy resources, transportation and electricity production Internal: extraction of energy resources, transportation and steam production		German-electricity-mix [12] Typical values for steam production in laundries, provided by Hychem GmbH [10]
Production of detergent ingredients', packaging and process chemicals	Extraction of raw materials, transportation and manufacturing of final chemicals	Packaging materials	The packaging materials are expected to be of minor impact due to re-use of containers
Transportation from chemical supplier to detergent manufacturer		All	Assumed to be of minimal impact
Detergent formulation	Formulation of finished detergents		
Textile production		All	Insufficient quantitative data available on differences in cotton life time for the three processes. Sterisan process, however, is known to have a lower tensile strength loss (TSL) per wash
Washing process	Washing of textiles		
Finishing		Pressing, drying, possibly ironing and folding the laundry	Finishing processes are assumed equivalent for the 3 compared processes
Internal waste water treatment		All	Internal waste water treatment is assumed to be nearly similar for the 3 processes and not to effect the results significantly
Municipal waste water treatment	Emissions of detergent ingredients after primary, secondary and tertiary treatment	All emissions and resource consumption related to the waste water treatment operation	Based on German situation [15] Emissions due to waste water treatment operation is assumed to be of minor impact.
Solid waste		All	To be neglected due to use of recycled containers. Solid waste is assumed to be equivalent for the 3 compared processes with respect to the relevant environmental indicators

comparable environmental burdens for each of the compared hygiene laundry processes. Excluded are: the laundry finishing process, the internal waste water treatment, production of tap water, transportation of detergent ingredients to detergent manufacturer, transport of detergents from detergent manufacturer to laundry; emissions produced by the waste water treatment operation and all aspects of packaging and solid waste treatment. Furthermore, it is common practice in LCA to also exclude capital goods and production infrastructure because these exclusions are not expected to affect the results of the LCA significantly [14,17].

Overall, the current LCA focuses on the comparison of the washing process and the detergent systems.

The geographical scope of the study was Germany. The study intends to represent the hygiene laundry sector of 2000–2004. Hygiene laundry textile volumes were retrieved from 2004. The intention was to use for all processes the most actual data available, not older than 5 years. However, for some processes only older data were available, e.g. various of the detergent production datasets date back to 1995 [15,18] and electricity generation data is based on data from 1996 [12].

1.2.3 Database and data quality requirements

For calculating the inventory results the Life Cycle Assessment software Umberto 4.0™ was used. This LCA software, in line with the relevant scenarios laid down, links modules and partial inventories with inventory networks and then makes calculations taking into account the relevant function unit laid down. It is described in detail in [11].

The scenario structure, inherent assumptions and calculation methods are described in Eberle 2002 [4]. The principle inclusions and exclusions in the systems studied are summarised in Table 3 and illustrated in **Fig. 1**.

The Life Cycle Inventory (LCI) data relating to major ingredients in the detergents used for the processes under investigation, such as the surfactants, have already undergone critical review processes and may be considered usable and reliable for the present screening LCA. This applies similarly to the general basis of data relating to energy supply, even if these do not undergo formal critical review. The LCI for peracetic acid and for PAP have only screening character because there were no inventories available to the authors for those two ingredients.

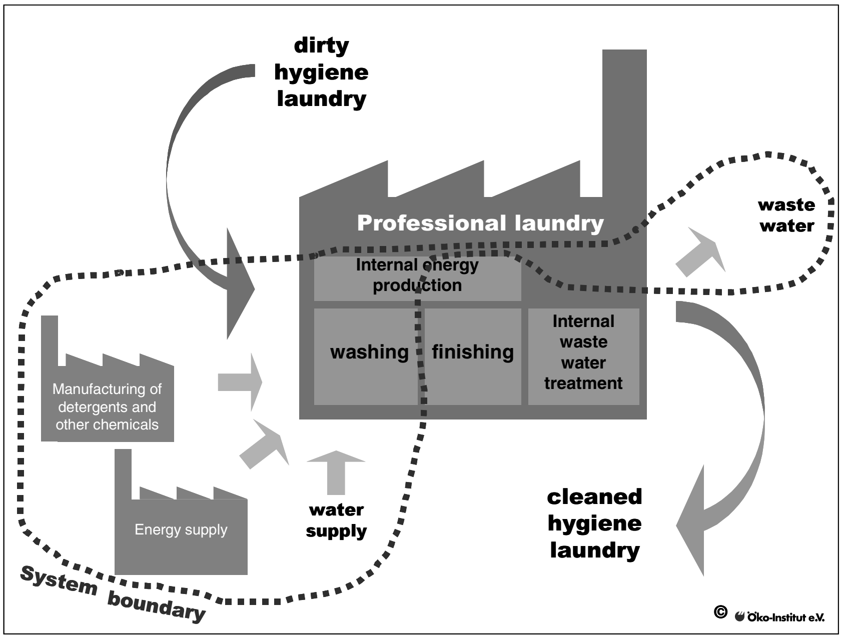

Fig. 1: System boundaries of the analysed system

The data sources for the LCI are reported in Table 1 and Table 2. In brief, they are received from the following databases: electricity production and the environmental emissions associated with it were either calculated using the BUWAL energy database [12], steam production was calculated using data provided in Umberto 4.0™ [11]. LCI information on raw materials was retrieved from various laundry detergent LCI publications [11–17], except for peracetic acid and PAP, for which screening inventories were developed [4]. LCI data for the manufacturing process of the detergents was based on a publication in Tenside Detergents [18], with a correction of the CO_2-emission data, which was described in a publication from Hychem GmbH [9]. LCI data for the laundry processes were obtained from Hychem GmbH/Steinau a.d. Str. and are documented in Table 1. LCI data associated with waste water treatment was from published German statistics [19] and specific data from a German waste water treatment plant [20].

1.2.4 Selection of impact categories

In general terms, Life Cycle Impact Assessment (LCIA) aggregates the emissions calculated in the life cycle inventory and translates these into potential impacts into the environment. To this end DIN EN ISO 14042 lays down that relevant impact categories must be selected (including the associated indicators and models), the Life Cycle Inventory results must be classified by category and subsequently their contribution must be taken into account through characterisation. These results together form what is called the impact assessment profile. Following paragraph explains the selection of LCIA methodologies.

Based on the objectives of the study, calculations were performed on following impact categories: climate change, acidification, eutrophication, stratospheric ozone depletion, photo-oxidant formation and aquatic eco-toxicity potential. Given the identified low relevance for the evaluated systems, impact results on ozone depletion was calculated, but not further reported in the conclusions. The human toxicity impact was not calculated at all due to methodological uncertainties and lacking input data. Furthermore, depletion of abiotic resources as baseline impact category was not calculated based on methodological issues for this type of study.

Due to the screening nature of this study and the need to compare with other washing processes, CML1992 [22] was used for aquatic eco-toxicity. This method allows pragmatical calculation of characterisation factors (CF) for chemicals specific for the systems studied and therefore allows good coverage of the ingredients. Herein, the CFs used for aquatic eco-toxicity were taken from CML1992 [22] and extended by various sources (cf. Table 6). Also, this method is historically used for ISO-compliant laundry detergent evaluations in Procter&Gamble [28] and therefore allows direct comparison with the products evaluated here. The authors recognise some of the inherent limitations of the CML1992 method, such as the fact that this method does not take into account environmental degradation and distribution.

For all other chosen impact indicators, CML2001 [21] was chosen as impact assessment method, characterisation factors for CML2001 method are based on datasets from 2004 [23].

The choice of the model for assessing aquatic eco-toxicity requires a few words of explanation. Various models for impact assessment are available today, with significant differences in underlying approach and data intensity.

Earlier research of Procter&Gamble in the OMNIITOX-project has demonstrated the issue of different aquatic eco-toxicity ranking of laundry detergents with similar input data when either EDIP 97 [24], USES-LCA (sometimes referred to as CML2001) [21,25] or IMPACT 2002 [26] were ap-

plied as LCIA method. Deviating results are mainly due to differences in the fate and exposure modelling approach and, to a lesser extent, to differences in the toxicological effect calculations. The main reason for deviating results remains in the calculation of the residence time of emissions in the water compartments [27]. Some characterisation factors of some laundry detergent chemical emissions into water have been developed for these methods, but these do not yet cover all relevant emissions from professional laundry detergents.

2 Inventory Analysis

The calculation methods to report the inventory results are described in [4]. The results of the simplified life cycle inventory of the three hygiene laundry washing processes investigated are presented in **Table 4**. All data are reported separately for detergent and disinfectant production and the washing process. The data for the waterborne emissions are also reported prior to municipal waste water treatment (w/o wwt) and after municipal waste water treatment (with wwt).

Table 4: LCI input and output for 1 kg of washed hygiene laundry by means of the thermal, chemothermal and Sterisan processes

		Thermal process		Chemothermal process		Sterisan process	
Energy consumption (CED) *							
Detergent & disinfectant production	kJ	472		497		679	
Washing process	kJ	2254		1698		368	
Total	*kJ*	*2725*		*2195*		*1047*	
Water consumption							
Detergent & disinfectant production	l	0.34		0.24		0.48	
Washing process	l	8.00		8.00		4.00	
Total	*l*	*8.34*		*8.24*		*4.48*	
Airborne emissions							
CO_2							
Detergent & disinfectant production	g	26		26		22	
Washing process	g	133		100		22	
Total	*g*	*159*		*126*		*44*	
SO_2							
Detergent & disinfectant production	g	0.12		0.15		0.08	
Washing process	g	0.10		0.07		0.02	
Total	*g*	*0.21*		*0.22*		*0.10*	
NO_x							
Detergent & disinfectant production	g	0.06		0.08		0.07	
Washing process	g	0.24		0.18		0.04	
Total	*g*	*0.30*		*0.26*		*0.11*	
Waterborne emissions		w/o wwt	with wwt	w/o wwt	with wwt	w/o wwt	with wwt
COD							
Detergent & disinfectant production	mg	10.1	0.6	13.9	0.8	16.6	1.0
Washing process	g	8.25	0.49	8.25	0.49	7.00	0.41
Total	*g*	8.26	0.49	8.26	0.49	7.02	0.41
BOD **							
Detergent & disinfectant production	mg	3.6	0.1	4.8	0.1	6.7	0.2
Washing process	ng	1	0.02	0.8	0.02	0.2	0.004
Total	*mg*	3.6	0.1	4.8	0.1	6.7	0.2
Tot-P							
Detergent & disinfectant production	µg	42.5	1.7	56.7	2.3	68.5	2.8
Washing process	g	0.4	0.02	0.5	0.02	0.03	0.001
Total	*g*	0.4	0.02	0.5	0.02	0.03	0.001
Tot-N							
Detergent & disinfectant production	mg	0.9	0.1	1.2	0.2	2.2	0.4
Washing process	µg	0.03	0.005	0.03	0.004	38400	6210
Total	*mg*	0.9	0.1	1.2	0.2	40.6	6.5
Ammonium							
Detergent & disinfectant production	mg	1.6	0.03	2.1	0.05	0.9	0.02
Washing process	pg	1.7	0.04	1.7	0.04	1.7	0.04
Total	*mg*	1.6	0.03	2.1	0.05	0.9	0.02

* The consumption of energy resources was inventoried on the basis of the *C*umulative *E*nergy *D*emand (CED). The CED expressed in kilojoules (kJ) specifies all fossil, nuclear and renewable energy sources as primary energy values and is calculated on the basis of the calorific value above. An overview of the calorific values used is included in [4]

** Measured BOD data for the waste water were not available

3 Life Cycle Impact Assessment

The impact categories included and methods used for LCIA in the study have been described in section 1.2.4. The results of the Life Cycle Impact Assessment (LCIA) reported on the basis of 1 kg washed hygiene laundry are shown in **Table 5**. All data are reported separately for detergent production (cleaning and disinfectant product) and the washing process. The impacts deriving from substances toxic to the aquatic environment are also reported before municipal sewage treatment (w/o wwt) and after municipal sewage treatment (after wwt).

To calculate the aquatic eco-toxicity potential, only the laundry detergent effluent to waste water treatment was included as these ingredients are responsible for over 99% of the aquatic eco-toxicity potential.

The waste water treatment model applied considers the current connection of the German hygiene laundry industry to primary treatment (only settler) and to secondary waste water treatment (activated sludge, trickling filter, etc.), which is respectively 1% and 99% [29]. The removal of each detergent ingredient by waste water treatment was taken into account to calculate the amount potentially discharged into the environment. The removal takes into account both elimination through biodegradation and the sorption on solids. Secondary emissions (sludge production, CO_2, etc.) and resource consumption from the waste water treatment operation are not included within the system boundaries.

Data sources for these removal values and for the characterisation (or effect) factors are sourced in a tiered approach (**Table 6**).

Where available, data for removal in primary treatment are sourced from reports covering studies in the Netherlands [30,31]. Removal by secondary treatment was mainly sourced through the EU Detergent Ingredient Database [32], which provides a ranking of detergent ingredients for use in European eco-label calculations. If no data were found there, characterisation factors were calculated based on eco-toxicity data from environmental risk assessment (ERA) reports and publications as listed in the table below. Whereas removal rates were calculated through waste water treatment model AS-Treat [33] which takes into account sorption, biodegradation and volatilisation. The water treatment software used is part of the TREAT system which is a set of two computer programs (SIMPLETREAT and ASTREAT) designed to quantify chemical pathways within wastewater treatment systems [34].

4 Interpretation and Discussion

4.1 Contribution analysis

Energy and water resources. The results show that the Sterisan process needs fewer energy and water than both

Table 5: Life Cycle Impact Assessment results for 1 kg of washed hygiene laundry by means of the thermal, chemothermal and Sterisan processes

		Thermal process		Chemothermal process		Sterisan process	
Global Warming Potential							
Detergent & disinfectant production	g CO_2-Eq.	26,5		26,7		26,4	
Washing process	g CO_2-Eq.	140,5		105,9		23,0	
Total	*g CO_2-Eq.*	*167,0*		*132,6*		*49,4*	
Acidification Potential							
Detergent & disinfectant production	g SO_2-Eq.	0.18		0.22		0.13	
Washing process	g SO_2-Eq.	0.24		0.18		0.04	
Total	*g SO_2-Eq.*	*0.41*		*0.40*		*0.17*	
Eutrophication Potential							
Detergent & disinfectant production	g PO_4-Eq.	0.009		0.012		0.010	
Washing process	g PO_4-Eq.	0.091		0.101		0.020	
Total	*g PO_4-Eq.*	0.100		0.113		0.030	
Photochemical Ozone Creation Potential							
Detergent & disinfectant production	g Ethylene-Eq.	0.091		0.113		0.078	
Washing process	g Ethylene-Eq.	0.320		0.241		0.202	
Total	*g Ethylene-Eq.*	0.411		0.354		0.280	
Ozone Depletion Potential							
Detergent & disinfectant production	g CFC-11-Eq.	2.01E-06		2.67E-06		1.56E-06	
Washing process	g CFC-11-Eq.	1.30E-14		1.30E-14		1.30E-14	
Total	*g CFC-11-Eq.*	2.01E-06		2.67E-06		1.56E-06	
Aquatic Ecotoxicity Potential		w/o wwt	after wwt	w/o wwt	after wwt	W/o wwt	after wwt
Detergent & disinfectant production	m³ water	not assessed		not assessed		not assessed	
Washing process	m³ water	2.28	0.10	3.06	0.14	75.0	2.18
Total	*m³ water*	2.28	0.10	3.06	0.14	75.0	2.18

Table 6: Overview of aquatic eco-toxicity of detergent ingredients through waste water treatment: CML1992 characterisation factors and removal in standard waste water treatment

Ingredient name	Characterisation Factor (m^3 polluted water per kg)	Removal Rate (%) (Primary treatment)	Removal Rate (%) (Sec/Tert treatment)
Alcohol (C13) ethoxylate, *EO < 5 (EO3)*	0.0056	29 [35]	97
Alcohol (C13) ethoxylate, *EO > 5 (EO7)*	0.0042	29 [35]	97
Polyoxycarboxylic acid, Na-salt	0.000009	20 [36]	60
Terpinolene	0.138 [37]	18.9 [37]	97.8 [37]
Oleic acid	0.0001	59 [35]	95
Nitrilotriacetate, Na-salt	0.000016	0 [36]	87
Diethylene-triamine-pentamethylen-phosphonic acid, Na salt	0.00004	60	60
Hexadecyltrimethylammonium chloride	0.0149 [38]	10 [36]	90 [38]
Fluorescer, distyryl-biphenyl type	0.001	55 [39]	60
Fluorescer, stilbene type	0.0001	55 [39]	60
Silicon-based antifoam	0.00021	60	60
Sodium hydroxide solution	0.00001	0	0
Potassium hydroxide solution	0.00001	0	0
Phthalimidoperoxyhexanoic acid	0.004 [40]	0 [36]	84 [36]
Methylhydroxyethylcellulose	0.000004	10 [36]	25
Hydroxyethylidenediphosphonic acid, sodium-salt	0.00004	60	60
Pentasodiumtriphosphate	0.000001	5 [36]	40-90 [36]
Peracetic acid (acetic acid in water)	0.00001 [36]	0 [36]	95
C13-15 alcohol ethoxylate-propoxylate, 14EO, 4PO	0.0028	29 [36]	95
Sodium metasilicate-pentahydrate	0.000001	10 [36]	20
Sodiumcarbonate	0.000004	10 [36]	20
Talc soap	0.0001	59 [35]	95
Zeolite P	0.0000057	50 [36]	95
Sodiumdisilicate	0.000001	10 [36]	20

Where not specifically mentioned, the Characterisation Factors (CF) and removal rates (RR) in waste water treatment were derived from EU DID list (Detergent Ingredient Database),values, i.e. using the Long Term Effect Concentration and Loading Factor, (more information on the criteria for EU eco-label is found on http://europa.eu.int/comm/environment/ecolabel/product/pg_did_list_en.htm).

other hygiene laundry treatment processes investigated (see Table 4 and **Fig. 2**):

- The total energy demand for production of chemicals and washing process can be more than halved using the Sterisan process. The Sterisan process is the only process for which the energy demand for washing is lower than for detergent and disinfectant production steps; the respective shares are 35% and 65%. This result is indicative of the considerable amount of energy required to heat the water to 90°C in the thermal process, in order to achieve disinfection. As shown in Table 4, the cumulative energy demand to produce the detergents and

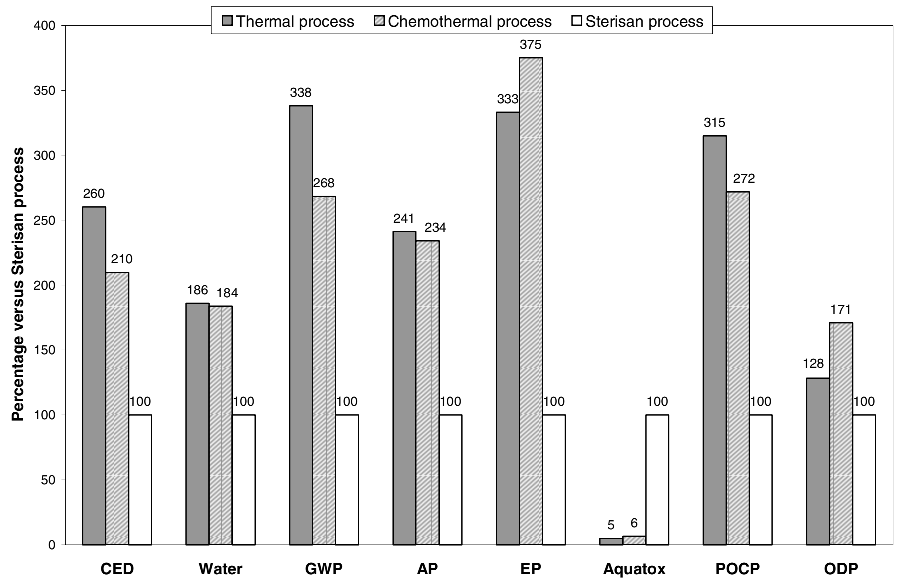

Fig. 2: Comparison of the three hygiene washing processes investigated. Numbers were normalised versus the Sterisan Process (per kg wash load)

disinfectant needed to wash 1 kg of laundry in the three processes investigated is highest for the Sterisan process (679 kJ) and lowest for the thermal process (472 kJ). In contrast, the CED for the washing process is highest for the thermal process (2,250 kJ) and lowest for the Sterisan process (368 kJ). The CED for the chemothermal process lays in between: 497 kJ for detergent and disinfectant production and 1,700 kJ for the washing process.

- The water demand can be nearly halved in the Sterisan process compared to the thermal and chemothermal process. This is due to the optimised bath current which can be used in the Sterisan process. The wash water can be reused in the prewash area because of to the lower temperature (40°C) and the lower active oxygen content. This way, protein fixing can be avoided unlike in the chemothermal and thermal process.

Life Cycle Impact assessment. When comparing the Sterisan versus the other processes, the LCIA indicates significant reductions for global warming potential, photochemical oxidant formation potential, acidification potential, eutrophication and ozone depletion potential, whereas the potential impact of Sterisan is significantly higher with respect to aquatic eco-toxicity (see Table 5 and Fig. 2):

- The global warming potential (GWP) is closely related to the energy demand. The GWP can be more than halved with the Sterisan process compared to the chemothermal process and is 3 times lower compared to the thermal process. Herein, the GWP for the detergent production (cleaning and disinfectant) is nearly the same for the three processes: approx. 26 g CO_2-Eq. However, when comparing the GWP of the washing processes, the results show that the GWP of the chemothermal and thermal processes are five to six times higher than when compared to the Sterisan process.
- The aquatic eco-toxicity potential of the Sterisan process is significantly higher than that of the thermal and chemothermal process: the contributions of the thermal and chemothermal processes are less than 7% than that of the Sterisan process. The aquatic eco-toxicity of the Sterisan process is dominated by a solvent component in the formulation, which causes nearly 80% of the aquatic eco-toxicity score. The scores of the thermal and chemothermal process are dominated by a surfactant component (approx. 60%).
- The photochemical oxidant creation potential (POCP) of the Sterisan process, mainly driven by VOC emissions and the washing process, is calculated to be 68% of the thermal and 79% of the chemothermal treatment.
- The results for the acidification potential (AP) are primarily driven by energy emissions: the environmental impacts caused by acidification are more than twice as high for the thermal and the chemothermal process. For the chemicals production the differences are less significant but during washing they are considerable: the AP for the thermal process is six times higher, while for the chemothermal process it is nearly five times higher.
- The eutrophication potential (EP) is dominated by the aquatic EP, and the environmental impact of the aquatic EP is dominated by the washing process. In the Sterisan process less eutrophicating substances are used. The highest EP is caused by the chemothermal process due to the quantity of phosphate detergent used, which ends up in the waste water. The EP of the chemothermal process is nearly four times higher than the EP of the Sterisan process, while the EP of the thermal process is more than three times higher. In the present study, P was present in the model formulations used for the thermal and chemothermal processes. It can be expected that eventually also P-free products will be developed for the classical wash processes in the hygiene laundry sector.
- Finally, also the ozone depletion potential (ODP) of the Sterisan process is calculated to be 80% of the thermal and 60% of the chemothermal treatment.

4.2 Estimation of contribution to overall environmental burdens through normalisation

The potential environmental advantages and disadvantages of substituting conventional technologies by Sterisan can be estimated on the basis of the total amount of hygiene laundry that needs treatment each year in Germany.

In order to better interpret the results from the LCI and LCIA, the first were normalised versus energy, water consumption and CO_2 emission datasets from Germany, the latter versus global normalisation datasets published for CML2001 [23] and CML1992 [41]. Also, for reference, the results from the 3 systems are compared to the results of a domestic laundry wash in the United Kingdom [42]. Although the datasets are subject to a certain level of uncertainty, they are indicative of the highest contributions to environmental topics of concern.

If all 58,4000 tons of hospital and care home laundry washed in Germany per year would be treated by Sterisan process as a replacement of an assumed 75% chemothermal and 25% thermal process.

The selected life cycle inventory indicators show that:

- More than 50,000 tons of CO_2-emissions could be avoided, corresponding to the average residential[1] CO_2-emissions of more than 36,000 citizens[2] or overall German CO_2 emissions equivalent to approx. 5,000 citizens[2]. When put in the context of the Kyoto protocol obligations, 0.02 percent of the Kyoto protocol reduction target of CO_2-emissions in Germany[4] could be achieved. Expressed for the CO_2-emissions of the hygiene laundry sector, 33 percent reduction could be achieved.
- More than 2 million m^3 of water could be saved, corresponding to the average water consumption of more than 30,000 citizens.[2]

[1] Residential energy includes all energy used for activities by households except for transportation, country specific energy consumption and production can be found at the international energy agency (2001, www.iea.org), country specific residential CO2 emissions are from CDIC/IEA/RIVM (1999, earthtrends.wri.org).
[2] As all reference values for normalisation of LCI indicators refers to German conditions, citizens in this chapter are referred to as German citizens.
[3] As all reference values for normalisation of LCIA indicators refers to global conditions, citizens in this chapter are referred to as world citizens.
[4] The Kyoto protocol obligations require a reduction of greenhouse gases by 21 percent between 1990 and until 2008, requiring an absolute reduction of 254 Mio tons in Germany until 2008. The Kyoto protocol was adopted 1997 in Kyoto and entered into force at 16 February 2005. (cfr. http://www.emissionstrategies.com/GHG/GHG_Tracker/germany.htm).

- Nearly 750,000 GJ of primary energy could be saved, corresponding to the average residential[1] primary energy demand of approx. 23,000 citizens[2] or overall German energy demand equivalent to approx. 6,000 citizens[2].

The life cycle impact assessment indicates that:

- The reduction in global warming potential would be equivalent to the global warming potential induced by approx. 8,000 world citizens[3].
- The increased emissions from the Sterisan process would be equivalent to the aquatic eco-toxicity potential caused by approx. 8,000 world citizens[3], which is 17 times higher compared to the thermal and chemothermal processes.
- The reduction in photochemical oxidant creation potential for the Sterisan process when compared to the current processes in Germany will be equivalent to the POCP potential produced by approx. 3,300 world citizens.[3]
- The reduction in acidification potential to be equivalent to that induced by approx. 2,600 world citizens.[3]
- The reduction in eutrophication potential to be equivalent to that induced by approx. 2,100 world citizens.[3]
- The reduction in ozone depletion potential to be non-significant (calculations indicate the savings to be equivalent to emissions produced by 7 world citizens[3]).

When comparing the professional laundry Sterisan process to environmental impacts of home laundry [14,28] per kg laundry treated, the Sterisan process

- needs approx. 4 times less primary energy resources and causes only 25% of CO_2-emissions,
- needs only a quarter of the water needed for home laundering
- produces only 30% of the substances toxic to the aquatic environment
- leads to an eutrophication and global warming potential which is only 20% of that of a domestic laundry wash
- but leads to a 4 times higher acidification potential and a 70% higher photochemical oxidant formation potential compared to a domestic laundry wash.

4.3 Sensitivity and uncertainty analysis

4.3.1 Study parameters

Water consumption. Water consumption in professional laundries can vary significantly between laundries [14,43], which is directly related to the energy need and the associated environmental burdens. Compared to data from Eberle and Möller [43], the values used in this study represent approximately sector averages. The assumptions for the water consumption influence the results of all analysed indicators, except for eutrophication, aquatic eco-toxicity and ozone depletion. It is specifically important for the energy demand and the energy related emissions as they are related to the amount of water to be heated. A reduction in water demand will lead to higher gains concerning energy related environmental impacts for the thermal process than for the chemothermal or Sterisan process.

A sensitivity analysis shows that even with a reduction of 50% in water consumption in the thermal and chemothermal washing process (from 8 litres to 4 litres per kg wash load) the primary energy demand remains higher than in the Sterisan process due to the higher washing temperature in both processes: the CED for the chemothermal process is about 30% higher, that for the thermal process about 75%.

Product Dosage. As the product dosage is based on equal performance (recommended dosage), no variations in product consumption are taken into account.

Phosphate-based detergent. The use of a phosphate based detergent in the thermal and chemothermal process causes a significantly higher eutrophication potential than the use of a phosphate free detergent. Obviously, any change in the detergents used in those two processes could lead to less environmental impact concerning the eutrophication potential. The market on the time of study was predominantly based on phosphate based detergents and still today phosphate based detergents are commonly used in hygiene laundry [44].

4.3.2 LCI database

Due to uncertainties in the LCI databases, differences in the evaluated LCI and impact categories are not considered significant if the difference is smaller than 20%, as a rule of thumb. However, in all scenarios larger differences are calculated.

4.3.3 Life cycle impact assessment

For well-established and recognised impact assessment methodologies like climate change, eutrophication, photochemical ozone formation, ozone depletion and acidification potential, no alternative methodologies have been considered. To calculate the aquatic eco-toxicity potential, it was opted to use CML1992 methodology since many characterisation factors for relevant ingredients were not available in CML2001. Whilst CML1992 provided 100% ingredient coverage for all hygiene laundry processes, CML2001 covered 88% of the chemothermal and thermal process, but only 46% for the Sterisan process. Therefore, a full assessment with CML2001 could not be conducted for this screening study.

Although the characterisation factors for the CML1992 method can be calculated, the different level of data availability and accuracy between ingredients leads to some (hidden) inaccuracies. For some chemicals with a limited fate and toxicity data availability, (i.e. terpinolene and PAP), the numbers are likely rather conservative and may lead to overestimation of the Sterisan aquatic eco-toxicity. One of the main ingredients driving aquatic eco-toxicity for the Sterisan process is terpinolene, which is considered responsible for 80% of the Sterisan process's aquatic eco-toxicity potential. Due to lack of chronic aquatic toxicity data, a safety factor of 100 was applied which leads to a characterisation factor of 0.138. This factor is 10 times higher then the next ingre-

dient characterisation factor (i.e. hexadecyltrimethylammonium chloride, CF=0.0149). A more in-depth discussion on the calculation of CFs based on data set with unequal quality can be found in the OMNIITOX report [27].

4.4 Limitations of the screening LCA

Following specific limitations of the screening LCA have to be mentioned:

- Packaging waste and its end of life treatment was excluded, as discussed under 1.2.2.
- For some ingredients, no LCI was available. For a number of other ingredients, it was possible to use a closely related LCI on a similar ingredient. This is the case for zeolite P used in the phosphate-based detergent, for which an inventory of a similar builder (zeolite A) from Dall'Acqua et al. 1999 [13] was taken. Also the different fatty alcohol ethoxylates used in the formulation of the detergents where all calculated as C13-alcoholethoxylate, 7EO. Such kinds of simplifications are common in LCIs due to the enormous variety of products and processes and the significant expense associated with conducting an actual inventorisation study. For ingredients where no LCI was available the approach depended on the share the ingredient had in the detergent or disinfectant formulation. Ingredients with a share less than 3% were left out in the LCI, whereas for ingredients with a share higher than 3% screening inventories were carried out. This was the case for phthalimidoperoxyhexanoic acid (PAP) and peracetic acid (see Table 2). The study would become more robust if these screening inventories could be validated in the future, but the results of the uncertainty analysis suggest that a detailed LCI for these ingredients is unlikely to change the general trend of the results.
- Technical studies [45] on tensile strength loss for these three processes have confirmed that the Sterisan process is milder to textile, i.e. after 50 Sterisan washes the tensile strength loss of cotton will be about three to six times lower than when washed with a thermal washing processes. As no information is available on how to link this dataset to an actual prolonged cotton lifetime, we have opted to leave this aspect outside the current study. Integrating this information within the system boundaries would allow for an even more realistic comparison of the three processes.

5 Conclusions

The screening LCA presented here indicates that the potential environmental impact for all indicators analysed, except aquatic toxicity, can be significantly reduced by introducing the Sterisan process in professional laundries. This step-change is made possible through the use of a bleaching and disinfection component (PAP), which allows reducing the temperature in the washing process. This leads to a reduction in energy and water demand and causes lower environmental impacts in global warming potential. Also the photochemical oxidant formation potential, acidification potential and eutrophication potential are reduced significantly by the Sterisan process compared with the other two hygiene processes investigated.

In contrast, the Sterisan process shows a much higher aquatic toxicity potential than the thermal and the chemothermal process. An improvement of this impact can be obtained by fine-tuning the chemical composition and potentially substituting the actual solvent used.

For the thermal and chemothermal process a major reduction of the environmental impact could be achieved by a reduction of the water consumption, which would lead to a lower energy demand in heating up the water used for washing, with positive effects on global warming potential and other associated emissions. The environmental benefits caused by electricity production could be reduced additionally by using green electricity, which obviously would be most beneficial for the thermal and chemothermal processes.

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